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Heterogeneous impact of livelihood diversification on household welfare: Cross-country evidence from Sub-Saharan Africa

Solomon Asfaw [a,*], Antonio Scognamillo [b], Gloria Di Caprera [c], Nicholas Sitko [b], Adriana Ignaciuk [b]

[a] Green Climate Fund (GCF), Independent Evaluation Unit, Incheon, South Korea
[b] Food and Agriculture Organization of the United Nations, Rome, Italy
[c] Centre for Economic and International Studies (CEIS), University of Tor Vergata, Rome, Italy

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ABSTRACT

This article investigates the empirical linkages between crop and livelihood diversification strategies, extreme weather events, and household welfare using a unique dataset that integrates harmonized, national representative household surveys and geo-referenced climatic information collected in Malawi, Niger and Zambia. In doing so, the paper addresses the potential endogeneity arising from the selection bias and the heterogeneity of the effect across the quantiles of the income distribution. Results show that exposure to extreme rainfall events is positively associated with either crop or livelihood diversification in all the countries analyzed, suggesting that climate-related shocks are key push factors for diversification. Moreover, results show that the effect of diversification on household income are varied across countries and diversification strategies. However, most of this heterogeneity disappears when estimating the quantile treatment effects. In particular, the results show that the impact of both crop and income diversification on households' welfare is generally higher for the poorest (people located at the bottom tail of the distribution) while it decreases, and in some cases turns to be negative, moving toward the upper end of the income distribution in all three countries. The findings, therefore, highlight the pro-poor impact of diversification strategies in multiple rural African contexts, as well as the need to tailor diversification interventions toward specific socio-economic segments of the rural population.

1. Introduction

The current and future impacts of climate change are a major source of concern in Sub-Saharan Africa (SSA), due to predominance of rain-fed subsistence-oriented agriculture in the region (Mendelsohn & Dinar, 2009; Seo, Mendelsohn, Dinar, Hassan, & Kurukulasuriya, 2009). The region is affected both by extreme weather events and by long-run climate variability, which can severely reduce yields and increase the levels of uncertainty with respect to agricultural production and output prices, leading to an overall increase welfare vulnerability of smallholders (IPCC, 2014).

Diversification of on-farm production systems and off-farm livelihood sources can help to spread the risk of climate-induced production and market uncertainty, and thus potentially increase farm households' resilience to these adverse events (Newsham & Thomas, 2009). Farmers can undertake different diversification strategies to manage risk, cope with economic and climate shocks, or escape from agriculture in stagnation or in secular decline (Zhao & Barry, 2014). For populations in more remote, marginal areas, where climate adaptation options are limited, diversification of agricultural production and/or income sources is one of the few viable strategy available to manage climate risks.

The choice of diversification pathway, both on-farm and off, can be conceptualized in terms of push and pull-factors, which are shaped by household-level socio-economic conditions, as well as the biophysical and institutional context within which farmers operate (Reardon, Berdegué, Barrett, & Stamoulis, 2006). Farmers are pushed into on-farm or off-farm diversification by a lack of alternatives for coping (ex-post) to the effects of a shock (i.e., extreme weather events, crop disease, unexpected price increase etc.) (Bandyopadhyay & Skoufias, 2013; Reardon et al., 2006); or to deal with the uncertainty of agricultural production (ex-ante) (Asmah, 2011; Babatunde & Qaim, 2009; Ellis, 1998, 2004; Ersado, 2003; Newsham & Thomas, 2009). Within this framework, both on-farm and off-farm diversification strategies can also be considered a safety-net, providing livelihood options in the context

* Corresponding author.
E-mail addresses: sasfaw@gcfund.org (S. Asfaw), antonio.scognamillo@fao.org (A. Scognamillo), gloria.dicaprera@uniroma2.it (G.D. Caprera), nicholas.sitko@fao.org (N. Sitko), adriana.ignaciuk@fao.org (A. Ignaciuk).

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of extreme events, particularly for the poorest households (Reardon & Taylor, 1996; Reardon & Vosti, 1995).

Distinguishing the potential effects of push versus pull factors on households' allocation of capital, labor and land is crucial to understand the welfare implications of different diversification strategies. In fact, depending on off-farm and on-farm income dynamics as well as the accessibility and development of agricultural markets, infrastructure, and information, the pathways may vary across countries and strategies. As a result, the drivers and the welfare outcomes of different diversification options may also vary significantly across countries, strategies and households (Asfaw, McCarthy, Paolantonio, Cavatassi, Amare, & Lipper, 2015).

This paper contributes to the growing area of research on diversification by considering three SSA countries, Malawi, Niger and Zambia, within the same conceptual and empirical framework. The similarities in terms of livelihood sources and exposure to extreme climate events, as well as the availability of rich datasets in these three countries, motivate the choice. The datasets used in this paper are harmonized, nationally-representative household level surveys merged with detailed geo-referenced climatic information at the smallest suitable resolution. The resulting empirical findings provide a comprehensive perspective to analyze different diversification strategies in different contexts and for different types of farmers.

The relevance of this study is twofold: Firstly, it provides a comprehensive, rigorous, harmonized, cross-country comparison on the drivers and the constraints of both crop and income diversification strategies and their impact on household welfare proxied by the total income.[1] Secondly, it disentangles the average effect to test the presence of heterogeneity across the income distribution.

The rest of the paper unfolds as follows. Section 2 discusses the regional context of SSA and the role of diversification of income sources and crops as part of rural livelihood strategies. Section 3 introduces the conceptual framework, which supports the empirical analysis. Section 4 presents the dataset construction as well as basic descriptive analysis. Section 5 explores the empirical strategy adopted for this analysis, while Section 6 shows the related results. Finally, Section 7 concludes and draws out the relevant policy implications of the analysis.

2. Diversification as a livelihood strategy in Sub-Saharan Africa

In the SSA region, agriculture represents the main economic activity in terms of employment and is carried out overwhelmingly under rain-fed conditions (Wani, Sreedevi, Rockstrom, & Ramakrishna, 2009). As a consequence, the economies of most countries in SSA, and the livelihoods of the majority of people, are highly vulnerable to climate change (Brooks, Adger, & Kelly, 2005). Without appropriate actions, this vulnerability is likely to deepen overtime as the climate continues to change. SSA is expected to be strongly affected by climate changes: future projections based on observed climate trends indicate that temperatures in SSA are consistently projected to rise faster than the global average increase during the 21st century (Christensen, Carter, Rummukainen, & Amanatidis, 2007; James & Washington, 2013; Joshi, Hawkins, Sutton, Lowe, & Frame, 2011; Sanderson, Hemming, & Betts, 2011). The development of resilient agricultural systems and rural livelihoods is, therefore, critical for countries in SSA to make progress on their economic development and food security (Niang et al., 2014).

Households exposed to climate risks have significant incentives to implement strategies, both on farm and off, to adapt to or cope with the effects of climate variability. This implies changes in a livelihood system, as well as in the learning process (Baird & Gray, 2014; Baird, Plummer, Haug, & Huitema, 2014), that lead to better risk management or coping capacity in the long run. Livelihood diversification strategies, including crop, and income diversification, are fundamental in these contexts (Doss, 2002). Moreover, gaining information on the nature and evolution of the climate risks faced by a society, represents a key aspect in choosing which diversification strategy to adopt (Brooks & Adger, 2004).

The empirical literature on this topic identifies a variety of diversification drivers and describes several examples of diversification practices. Some studies tend to interpret the diversification process as a deliberate ex-ante strategy aimed at producing income gains by enriching the portfolio of economic activities (Ellis, 1999). In the case of SSA, this argument is supported by the high share of rural household's income derived from non-farm activities (Barrett, Reardon, & Webb, 2001; Davis et al., 2010; Dixon, Gulliver, & Gibbon, 2001; Ellis, 2009). In the case of income source diversification, households with larger initial endowments, more educated members and shorter distances from main markets are more likely to be pulled into a range of off-farm activities with the aim of increasing or stabilizing household incomes and augmenting low returns in traditional core activities (Barrett et al., 2001; Block & Webb, 2001). In addition, the availability of cash crop markets can pull households into crop diversification pathways that produce productivity gains and allow farmers to move from subsistence agriculture to trade-based agriculture with net income and welfare gains (Bandyopadhyay & Skoufias, 2013; Di Falco & Chavas, 2009; Pingali & Rosegrant, 1995).

On the other hand, households can be pushed into diversification pathways in response to climate extreme events and other shocks (i.e., crop disease, unexpected price increase etc.). For the poorest households, who have the least capacity to effectively cope with risk, diversification is often one of the few viable options available to manage the challenges associated with climate risk. In this sense, the poorest are pushed into diversification by a lack of alternatives for risk coping. In regions where rainfall variability is high, households may decide ex-ante to diversify their income with the final aim to manage the risk of possible shocks or diversify ex-post to make up for production deficit (Bandyopadhyay & Skoufias, 2013; Reardon et al., 2006). Ultimately, how household's respond to these push factors depends on their characteristics, which can influence their understanding of these events (Barrett et al., 2001; Ellis, 2004; Reardon et al., 2006) and the range of options available to respond to them.

There is emerging consensus in the literature that during the last decades the number of rural smallholders in SSA that have diversified their sources of income and/or their agricultural production has constantly increased either to cope with the climate risks or to take advantage of market or infrastructural developments (Reardon, 1997a, 1997b; Barrett et al., 2001; Losch et al., 2012; Losch, Magrin, & Imbernon, 2013, Loison, 2015). However, there remains considerable debate over whether on-farm and off-farm diversification contributes to an increase standard of living in SSA countries (Loison, 2015).

Several studies have investigated the effects of adaptation strategies to stabilize the livelihoods of rural communities. Among these, different types of diversification emerge as an effective strategy to mitigate the impact of extreme events and climate

[1] It's important to note that the livelihood's literature developed in the early 2000s analysed the income generated from on-farm activities separately from the income generated from off-farm income sources, which are often disaggregated. This strand of the literature highlights that the drivers and the nature of these off-farm activities are inherently different and are likely to affect differently the household welfare of different types of households (for an extensive review of this literature see Lipper & Cooper, 2015). In our case the lack of disaggregated data on off-farm income sources across the different countries with the same granularity create challenges to undertake the cross-country comparison that is one of the main objectives as well as one of the main contributions to the literature of this study.

variability and to deal with uncertain agricultural production while maintaining ecosystem functions and income benefits for smallholder farming communities (Asmah, 2011; Babatunde & Qaim, 2009; Bozzola, Smale, & Di Falco, 2018; Ellis, 1998, 2004; Ersado, 2003; Newsham & Thomas, 2009). Others, however, have shown that some diversification pathways can contribute to a reduction in welfare opportunities, by locking households into a diversified, but low-return, set of activities (Reardon, Taylor, Stamoulis, Lanjouw, & Balisacan, 2000; Lohman & Liefner, 2009).

Identifying which set of factors drive rural household diversification choices will provide insight into the role of diversification, either as a matter of necessity to reduce food insecurity and exposure to extreme poverty, on the one hand, or as a choice and opportunity for improving standards of living on the other (Dimova & Sen, 2010). Furthermore, the heterogeneity characterizing the drivers of diversification is likely to shape the distribution of the welfare gains arising from these strategies among different farmers. Given that, investigating the welfare impact across different quantiles of the household farmers income distribution is necessary to support evidence-based policies in SSA.

3. Conceptual framework

The theoretical foundation of this study is the Sustainable Rural Livelihoods (SRL) conceptual framework (Bebbington, 1999; Ellis, 1999; Martin & Lorenzen, 2016; Niehof, 2004). By considering diversification of income sources and crop as strategies for smallholder households to manage adverse impacts on income and food security caused by extreme climatic events, uncertain agricultural production and unexpected market shocks (Asmah, 2011; Barrett et al., 2001; Di Falco & Perrings, 2005; Morduch, 1995), this study investigates the impact of diversification on rural households' welfare (proxied by the household gross income).

We refer to smallholder households as a decision-unit agent operating in a poorly integrated environment although characterized by a certain degree of heterogeneity with respect to the degrees of infrastructural and institutional access. These heterogeneity determines the cross-country differences of the drivers of each strategy at country level as well as the distribution of the welfare gains (losses) across different quantiles of the income distribution. In this framework smallholders seek to manage potential climatic or market-related risks by diversifying their portfolio of income source (including on-farm and off-farm activities) and agricultural production.

In so doing, the farmer expects to achieve productivity gains (Di Falco & Chavas, 2009; Pingali & Rosegrant, 1995), to insure against risks *ex-ante*, and/or to cope with negative impacts on welfare *ex-post*[2] (Ellis, 2000; Kelly et al., 2000; Eriksen, Brown, & Kelly, 2005). It is worth noting that, while the *ex-ante* diversification can be planned so that an expected potential challenge can be faced, the *ex-post* diversification represents a feedback action to an unanticipated shock shrinking the households' welfare (Ellis, 2000; Eriksen et al., 2005; Kelly & Adger, 2000).

Given that, the degree of diversification (either on-farm or off-farm) is driven by their degree of risk aversion which is, in turn, linked to the endowment of assets to which the household i has access to at time t (Carney, 1998). We can represent them as a vector of strategic capitals K for which:

$$K_{it} = \left\{K_{it}^{N}, K_{it}^{P}, K_{it}^{H}, K_{it}^{F}, K_{it}^{S}\right\} \qquad (1)$$

[2] The timing of such a response to potential shocks also depends on household characteristics determining the perception and awareness of involuntary anomalies (Barrett & Reardon, 2001) as well as on their inter-temporal discount rate, while the extent to which they expect climatic or market shocks is related to past long or short-term experience with such shocks (Adger et al., 2009).

In this framework K_{it}^{N} stands for natural capital (e.g. cultivated land), K_{it}^{P} represents physical agricultural assets (e.g. tractors, transportation), K_{it}^{H} is human capital (e.g. education, gender), while K_{it}^{F} and K_{it}^{S} are vectors of financial (e.g. credit access) and social assets (e.g. networks), respectively (Ellis, 2000; Scoones, 1998).

These assets contribute to define the livelihood options available to farmers and are correlated in explaining drivers of diversification (Cinner, McClanahan, & Wamukota, 2010; Nguyen et al., 2017). For instance, a land-endowed farmer, with limited access to agricultural inputs or to credit, could rely on crop diversity as a substitute input for chemical fertilizers (Bellon, 2004). On the other hand, households with adequate levels of human or social capital may be pulling into alternative off-farm income sources. In the case of sub-Saharan regions and, particularly in the three countries of interest, the evidence of such mechanisms is confirmed by the increasing income shares of non-farm activities in rural households as a response to low returns in traditional core activities (Barrett et al., 2001; Block & Webb, 2001; Davis et al., 2010; Ellis, 2009). Given that, the background of the SRL has been adapted to a simplified non-separable farm household model in which on-farm crop diversification and off-farm income-generating activities are simultaneously determined and affected by the same set of exogenous expected or unexpected shocks and asset endowments (de Janvry, Fafchamps, & Sadoulet, 1991; Wouterse & Taylor, 2008).

In a risky environment, the household welfare is subject to infrastructure development and market integration, represented by P, as well as potential shocks S, and could be represented as:

$$W_{it} = f[D_{it}[(P_t, S_{t-\tau}, K_{it}); Z_{it}] \qquad (2)$$

In this framework, welfare W_{it} for household i at time t, that in the empirical analysis is proxied by the household income, is a random variable, in which the vector of crop and income diversification D represents a viable livelihood strategy that households adopt as a consequence of (a) pull factors such as the proximity to markets or to other farmers adopting the same strategy, P; (b) push factors such as the need to be insured or to cope against S over a time span defined by τ; (c) the endowment and other socio-economic characteristics K and unobserved factors Z.

4. Data description

As primary source of data, we rely on nationally-representative datasets in Malawi, Niger, and Zambia, each providing socio-economic indicators. Specifically, we deal with three panel-structured datasets. Although a growing number of empirical contributions have taken advantage of the increasing availability of large-scale household panel data, merging them with granular climate information (Abdulaia & CroleRees, 2001, Asfaw et al., 2014; Asfaw et al., 2015; Asfaw, Pallante, & Palma, 2018; Dzanku, 2018, among others), to the best of our knowledge, this type of data setting has been rarely used in a cross-country perspective. This is probably because the harmonization of large nationally representative survey data is time and labor intensive and, in most cases, it is simply not possible due to the surveys' heterogeneities.

In Malawi, household-level data comes from the Integrated Household Panel Survey (IHPS), which is carried out by the Government of Malawi through the National Statistical Office and supported by the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) initiative. The household survey consists of a multi-topic questionnaire aimed at collecting information on household characteristics, health, wage, consumption, food security, agricultural assets and production. The final panel sample of the IHPS is shaped from the third wave of the IHS (IHS3) that was conducted in 2010/2011.

Table 1
Data sources.

Country	Year	Type of data	Data Sources	Climatic Variables
Malawi	2010–2013	Panel	Malawi Integrated Household Panel Survey (IHPS)	Africa Rainfall Climatology (ARC 2), 1983–2014
Niger	2011–2014	Panel	Niger National Survey on Living Conditions and Agriculture (ECVM/A)	Africa Rainfall Climatology (ARC 2), 1983–2014
Zambia	2012–2015	Panel	Rural Agriculture Livelihood Survey (RALS)	Africa Rainfall Climatology, (ARC 2), 1983–2014

In Niger, we exploit original panel socio-economic data obtained from the Niger National Survey on Living Conditions and Agriculture (ECVM/A, 2011). We build a longitudinal dataset by appending information obtained from the first survey visit in 2011/2012 with that obtained from the second visit in 2014. The ECVM/A is an integrated multi-topic household survey which provides rich information to evaluate poverty and living conditions in Niger. The surveys were implemented by the Niger National Institute of Statistics with technical and financial assistance provided by the World Bank. Each wave envisages two visits, the first one during the planting season, and the second one during the harvest season. For our analysis, we pooled these two sources of information in order capture the full cropping cycle as well as to be consistent with other country surveys. The ECVM/A has been designed to have national coverage, including of both urban and rural areas, with a fine spatial breakdown (270 enumerator areas divided by urban areas, rural areas, and within the rural areas, agricultural zones, agro-pastoral zones and pastoral zones).

The nationally-representative household data for Zambia come from the 2012 and 2015 waves of the Rural Agricultural Livelihoods Survey (RALS) collected by the Central Statistics Office (CSO) in collaboration with Michigan State University (MSU) and the Indaba Agricultural Policy Research Institute (IAPRI). The survey includes detailed information on agricultural production and sales, off-farm activities and other income sources, along with household demographic characteristics as well as social capital indicators.

Taking advantage of the geo-referred information contained in these surveys, the socio-economic data have been combined with granular information on precipitation collected at enumeration areas (or at ward level in the case of Zambia) from the Africa Rainfall Climatology Version 2 (ARC2) of the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA-CPC) database covering each decade of the period 1983–2014. Table 1 reports the sources of both household-level and climatic data for the three countries of interest for this work.

The empirical analysis relies on a limited but harmonized set of information for each of the three countries analyzed. This feature allows to ensure the highest degree of comparability among the results arising from the cross-country exercise.

In this paper, we distinguish two different diversification strategies: of crop production and income sources. The household diversification level in each dimension is computed through the Gini Simpson index which is continuously distributed and ranges from 0 to 100. The crop diversification index is based on the number of cultivated crop species adjusted by land size at the plot level in each of the three countries considered. Similarly, the income diversification index is based on the number of income sources at household level, adjusted by the total household income. It is worth highlighting that Gini index for income diversification is computed using two scenarios. The first scenario included all sources of income including agricultural income whereas the second scenario included only non-agricultural income sources. Results of both scenarios are reported in this paper although the latter have been reported in Appendix III as robustness checks of the results obtained with the previous.

As for the household welfare, given the limited availability of other welfare indictors that are comparable cross-countries, this study focuses on the economic dimension and specifically on income. The possibility of heterogeneous diversification behaviors according to the gender of the household head has been considered including a dichotomous variable identifying a female household head.

Table 2 reports descriptive statistics for all the variables considered in this study, allowing for a full cross-country comparison. The figures provide a comprehensive scenario of the diversification strategies as well as information on the similarities and the specificities in each of the selected SSA countries. The average level of crop and income diversification is quite similar in Malawi (41% and 32%, respectively) and Zambia (43% and 30%, respectively) while it is substantially higher in Niger (55% and 46%, respectively). The average risk exposure to negative shocks is substantially higher in Malawi (9%) relative to the other two countries.[3] The relatively lower level of diversification in Malawi is also reflected in a lower levels of diversification at an enumeration area level—what we refer to as peer effects– where the percentage of households that diversify either their agricultural production and/or their income sources is about 10% smaller relative to Niger and 7–8% smaller relative to Zambia. The average household size is smaller in Malawi (5.19 household members) than in Niger (6.87 household members) or in Zambia (6.72 household members). However, in Malawi, household heads are on average younger (45 years) relative to Niger (45.98 years) and Zambia (47.63 years), and the percentage of female household heads is substantially higher (25%) than Niger (9%) and Zambia (19%). As for the human capital, proxied by the level of education of the household head, Malawian farmers are slightly more educated than their Zambian counterparts (6.32 years of schooling in Malawi against 6.05 in Zambia) and both are on average much more educated than in Niger, where the average years of schooling of the household head is only about 1 year.[4] Another relevant difference across countries is related to the average land size. In Malawi, due to a strong demographic pressure, the average cultivated land size is smaller than 1 ha (0.75 ha), less than in Niger (4.66 ha) or in Zambia (2.41 ha). For all the other variables, the comparison of the average values is not very significant since they depend on the intrinsic characteristic of each country.

5. Empirical strategy

To estimate the drivers of diversification, a multi-equation seemingly-unrelated regression (SUR) model has been estimated using random effects in the context of unbalanced panel data. This approach provides efficient estimations considering the potential correlation between the error terms of the equations of each diversification strategy. In our framework, the empirical model consists of specifying a two-equation model for each country, in which the dependent variables measuring the degree of crop and income diversification are regressed over a set of common exogenous predictors. Specifically, for each $i = 1 \cdots N$ households, the two-equation model assumes the following form:

[3] It is worth noting that, since the index has been calculated relatively to historical information in each country, a higher index does not entail having experienced more shocks in absolute term.

[4] Although education is compulsory between the ages of seven and fifteen, Niger has one of the lowest literacy rates in the world.

Table 2
Descriptive statistics.

	Malawi				Niger				Zambia			
	Mean	N	Min	Max	Mean	N	Min	Max	Mean	N	Min	Max
Diversification												
Crop diversification index	41.53	3782	0	84.75	54.83	2285	0	84.38	42.96	11,152	0	85.54
Income diversification index	32.85	3443	0	79.53	45.70	1907	0	78.54	30.02	11,151	0	76.60
Outcomes												
Total household income (local currency)	126,063	3568	0	58,682,576	843,188	2367	0	39,235,000	15,436	10,838	416	244,176
Climate variable												
Long-term risk of negative rainfall shocks (SPI < −1.5)	9.05	3788	3.57	19.23	4.40	2367	0	13.33	6.42	11,152	0	19.23
Peer effects												
% of crop diversification within the EA	73.76	3782	0	93.75	82.05	2285	0	94.44	80.81	11,152	0	97.06
% of income diversification within the EA	76.24	3443	0	93.75	85.04	1907	0	94.44	84.06	11,151	0	97.14
Household socio-demographic												
Age of Household Head	45.17	3734	20	87	45.98	2330	21	80	47.64	10,949	24	84
Household size	5.19	3788	1	17	6.87	2367	1	30	6.72	11,152	1	30
Female Household Head	0.25	3788	0	1	0.09	2367	0	1	0.19	11,152	0	1
Human, natural and physical capital												
Household head level of education (years of schooling)	6.32	2887	0	19	1.05	2367	0	15	6.05	11,152	0	19
Land size (hectares)	0.75	3717	0.05	2.87	4.66	2320	0.12	21.39	2.41	10,943	0.2025	12.0
Wealth Index	0.28	3788	0	1	0.02	2344	0	0.36	0.10	11,045	0	0.7
Institutions and infrastructures												
Agriculture Extension officer	0.28	3788	0	1	0.02	2237	0	1	0.75	11,152	0	1
Market access (Km distance from periodic the market)	0.55	3788	0	1	20.80	2345	0	140.00	24.73	10,917	0	120
Road access (Km distance from the road)	8.04	2255	1	42	31.57	2346	0	140	27.03	10,844	0	180

$$\begin{cases} D_{it1} = \beta_0 + X_{it1}\beta_i + a_i + u_{it1} \\ D_{it2} = \beta_0 + X_{it2}\beta_i + a_i + u_{it2} \end{cases} \quad with\, i = 1\ldots N \quad t = 1,\ldots,T; \tag{3}$$

where the dependent variables D_{it1}, and D_{it2} indicate, respectively, crop and income diversification respectively for the household i at time$t$. The set of independent variables in all equations includes a series of common exogenous controls represented by vector X_{it} affecting the degree of diversification as well as a vector a_i, representing the unobserved individual-level effects. Finally, the parameter u_{itj} represents the observation-specific error in the equation j. The SUR models assume that the overall variance-covariance matrix between the errors in each equation of the system is different from zero, i.e. $\Omega = E(uu') = \sum \otimes I_N$. Therefore, the simultaneous estimation of the model is expected to increase the efficiency of the results.

The model controls for natural capital, including a variable capturing the land cultivated expressed in hectares (Nguyen et al., 2017). The physical, technological (e.g. tractors and machinery), and non-technological agricultural inputs (e.g. shovel, spade) are proxied through a composite wealth index. The risk exposure to negative rainfall shocks is estimated using the 30-year historical series of rainfall during the three months leading up to the peak of the rainy season. In particular, the index is given by the percentage ratio between the number of years in which the estimated Standard Precipitation Index (SPI) was below the threshold of −1.5 over the total number of years preceding the reference period. The model also controls for locational peer effects both for crop and income diversification using the leave-out percentage of diversified households (i.e. households with the considered diversification index greater than 0) within the enumeration area (Townsend, 1994). Moreover, a set of controls at the community level are included to proxy infrastructure development (distance from periodic markets and from the nearest road), and several dummies at the regional level are included to capture locational-related heterogeneity across households. Finally, the availability of information from the agricultural extension officers has been captured through a household-level dummy variable that takes the value of 1 if the household has received information on diversification from this source and 0 if otherwise.[5]

As for the local average treatment effect, the causal relationship between diversification and households' welfare has been estimated using the instrumental variable (IV) technique. Specifically, a two-equations system for each diversification index,c, has been estimated.

$$\begin{cases} D_{cit} = \beta_0 + \beta_1 \mathbf{Z}_{kcjt} + \beta_i X_{it} + a_i + u_{cit1} \\ Y_{it} = \beta_0 + \beta_1 \widehat{\mathbf{D}}_{cit} + \beta_i X_{it} + a_i + u_{it2} \end{cases} \tag{4}$$

where Y_{it} represents the total income of household i at the time t; D_{cit} represents our endogenous variables and, thus, the different drivers of diversification (crop, and income) which are correlated with the error component u_{it2}.

Several reasons motivate concerns with endogeneity. The first is reverse causality: While diversification affects household income through risk reducing mechanisms, the reverse might also be true because households' initial level of welfare is likely to affect their probability of overcoming entry barriers and liquidity constraints to the implementation of diversification strategies. Moreover, another source of endogeneity is due to our inability to observe farmer characteristics such as entrepreneurial skills and openness to innovation. In this framework, finding variables that satisfy the necessary IV requirements is the main challenge to establishing a causal relationship between the dependent and the endogenous explanatory variables in a non-experimental setting. To remove the bias, this study relies on two sets of variables which affect the drivers of diversification, but do not have any direct impact on welfare outcomes. $\mathbf{Z}_{kcjt}$ is a vector of k instruments varying according to the nature of the diversification index, c, within each enumeration area $j$for each period t. The first instrument is related

[5] The analysis is based on such a restrictive specification to ensure cross-country comparability. Robustness checks using a wider set of controls according to the data availability in each country produce similar results and are available upon request.

to the probability of suffering a rainfall shock (Di Falco & Veronesi, 2013) that for in this study is based on the SPI index calculated using historical series of precipitation during the three months preceding the peak of the rainfall season in each country.[6] Since we excluded the considered year *t* from the SPI calculation, the index is expected to be correlated with the diversification index at the household level but not to be correlated with the source of unobserved heterogeneity and to not have any direct effect on household income in the survey reference year. When necessary to the model identification, the empirical strategy takes advantage of an additional excluded instrument that is the percentage of households in the community (excluding the household considered) adopting the considered diversification strategy (whose diversification index is greater than zero). In the spirit of Townsend (1994), the leave-out mean at household level is expected not to be correlated with the household unobserved heterogeneity and the household outcome variable. (Wooldridge, 2010).

The complete results from the first stage, including the tests on the validity and the relevance of the instruments are reported in Appendix I. In particular, the structural model identification has been tested by the Anderson Rubin Canonical statistic (IDSTAT) and the related test (ID-P). In all the cases analysed, the tests have rejected the null hypothesis of under-identification.[7] In the case of Malawi, since the model include two exclusion restrictions, the joint validity of the instruments has been tested through the SARGAN statistic and the related test (SARGAN-P). However, although the structural models are always identified, in a number of cases, the F-test alerts about the weakness of the excluded instruments. In all these cases, we have tested the robustness of the inference obtained with weak instruments through two different tests, namely Anderson-Rubin (AR-P) and Stock-Wright (SSTAT-P). Both the tests confirm the robustness of the inference with weak instruments by rejecting the null hypothesis that the excluded instruments are jointly equal to zero in the main equation.

Finally, this paper addresses the distributional effects of diversification strategies. Implementing this methodology, we aim to test if the same diversification strategy could be either welfare-enhancing or detrimental at different levels of the household income distribution. In order to account for this potential heterogeneity, the baseline model has been reformulated as a quantile treatment regression model for panel data. Following Chernozhukov and Hansen (2005), the quantile outcome is related to its quantile function as:

$$\mathrm{Y_{it}} = q(D_c, X_i, U_d) \tag{5}$$

where the dependent variable is conditioned to five sections of the distribution (q = {0.1,0.25,0.5, 0.75, 0.9}), D is the endogenous variable which identifies a diversification strategy, *X* is a vector of household, institutional, and geographic observed characteristics, and U_d is the rank variable, which determines the outcome heterogeneity among individuals with the same observed characteristics and treatment state located at different levels of the outcome distribution. The model has been estimated following Powell (2016), which uses within-individual variation for identification purposes but maintains the non-separable disturbance property $U_d|\ D \sim Uniform(0,1)$ (i.e. the individual fixed effects are not additive which allows to interpret the results in the same manner as cross-sectional quantile estimates).[8] This methodology is suitable for this study since it is developed in an instrumental variables framework and the fixed effects are allowed to have an arbitrary relationship with the instruments.[9] It is worth highlighting that for statistical purpose, we also show the results from random-effect, fixed effect and correlated random effect models for the local average treatment effect estimator (IV-FE). Similarly, the estimated endogenous quantile treatment effects (IV-FE QTE), have been reported using the result from a quantile exogenous treatment (FE-QTE) estimator as a yardstick.

6. Results

This section presents the results obtained in the three countries analyzed using both the crop and the income diversification indexes.[10] To pave the way for a comparison among them, the interpretation of the results are focused on the cross-country similarities and specificities. The same specification has been estimated for the three countries separately, and each variable included in the analysis has been defined similarly.

6.1. Drivers and constraints to diversification

The drivers of crop and income diversification are estimated simultaneously through a one-way random effect estimation of seemingly-unrelated regressions model. Table 3 reports the full set of the estimated results from the three countries.

The empirical results confirm that exposure to extreme dry events acts as a push factor for crop diversification in Malawi and Niger, while the association is negative in Zambia. However, the exposure to the risk of extreme dry shocks is not a driver for any income diversification strategy in Niger and Malawi while it is positively related with income diversification in Zambia. The differences between Malawi and Niger on the one side and Zambia on the other suggest a substitutability relationship among these two strategies depending on the interaction between household farmers' characteristics and context-specific infrastructural and institutional features.

As for the peer effects, the findings show that households located in areas characterized by a higher percentage of farmers adopting a specific diversification strategy exhibit higher levels of diversification. For Malawi and Zambia, the higher the percentage of population surrounding the household and implementing any of diversification strategy, the higher the probability that the household diversifies either the crop production or the income sources. It is worth acknowledging that given the limit of the empirical analysis, these results could depend either on peer-to-peer sharing of information among farmers or could be due to other unobserved features that are homogenous at the same geographic level of aggregation. As an example, the geographic areas where more diverse farm systems are located may also be the areas where

[6] In our framework, we consider only the dry shocks such as droughts. According to McKee et al. (1993, 1995), an extreme dry episode is identified when the SPI index is smaller than −1.5.

[7] When the structural model was under-identified with only one exclusion restriction (as in the case of Malawi), an additional instrument has been added.

[8] i.e. the treatment effect of the explanatory variables on the τ^{th} quantile of the outcome distribution.

[9] The generalized quantile regressions in Niger and Zambia have been estimated using an adaptive Markov Chain Monte Carlo optimization procedure by setting 10,000 random draws (5000 have been dropped as burn in period), 50% of acceptance rate and a conservative adaptation of the proposal distribution. In Malawi, due to some convergence issues, the model has been estimated by setting 50,000 random draws (10,000 of them have been dropped as burn in period), 50% of acceptance rate and a strongly conservative adaptation of the proposal distribution (dampparm = 0.01).

[10] In order to test the robustness of the empirical results related to the income diversification index, the complete analysis has been also implemented by calculating the income diversification including only non-agricultural income sources. The complete results of this robustness check are reported in Appendix III. The main findings of this analysis do not overturn the findings obtained using an index of diversification which include both on-farm and off-farm activities. However, the differences between farmers at different quantile of the income distribution are attenuated and the trend is not always monotonically decreasing moving from the bottom to the top, when only the off-farm income sources are considered.

Table 3
Drivers and constraints by country and diversification strategy.

	Malawi		Niger		Zambia	
	Crop	Income	Crop	Income	Crop	Income
Climatic variables						
Long-term risk of negative rainfall shocks	0.396*	−0.044	0.775***	0.140	−0.592***	0.244***
Peer effects						
% of crop diversification within the EA	0.326***	0.063*	0.485***	0.033	0.576***	−0.084***
% of income diversification within the EA	0.072*	0.311***	−0.030	0.227***	−0.095***	0.322***
HH Socio demographic						
Age of Household Head	−0.153***	−0.021	0.032	0.150***	0.078***	0.008
Household size	0.219	0.590**	−0.028	0.032	0.041	0.434***
Female Household Head	−0.110	−1.862	1.506	0.044	−1.678***	1.762***
Human, natural and physical capital						
Household head level of education	−0.212	−0.497***	0.163	−0.200	−0.229***	0.588***
Land size	13.071***	0.582	0.649***	0.235	0.505***	−0.634***
Wealth Index	10.735***	10.270***	15.117	23.379	−2.322**	12.590***
Institutions and infrastructures						
Agriculture Extension officer	3.215**	0.507	6.941***	0.896	1.792***	1.466***
Market access (distance from periodic the market)	−0.202**	0.071	−0.015	−0.002	0.002	−0.039***
Road access (distance from the road)	0.138**	−0.030	0.014	0.093***	0.023***	0.014**
Year dummy	YES	YES	YES	YES	YES	YES
Regional/AEZ dummies	YES	YES	YES	YES	YES	YES
Random effects	YES	YES	YES	YES	YES	YES
Simultaneous estimates	YES	YES	YES	YES	YES	YES
Observations	1478		1658		10,198	

Note: Significance levels (***p < 0.01, **p < 0.05, *p < 0.10).

cultural food preferences are more varied, where private investments in markets are more robust, or where food reserve agencies are less prevalent.

As for the production factors, family size is a potential indicator of labor supply for production, which is expected to increase the level of income diversification. Consistently, the results show that larger households diversify income more in Malawi and Zambia but not in Niger. On the other hand, the availability of land is expected to be an enabling factor for crop diversification. The findings confirm the expectations since the extent of the cultivated land is positively related with the crop diversification level for the three countries. The differences in the size of the coefficients related to this variable across the countries are likely to be due to the substantial differences in terms of land endowment between Malawi on one side and Niger and Zambia on the other.

The empirical relationship between diversification and human capital (proxied by the education level of the household head) and economic capital (proxied by a wealth index) are unclear a priori. On the one hand, wealth and education could increase diversification, as more educated and wealthier households may have greater capacity to explore off-farm labor and new income opportunities, as well as to adopt more diversified crop production systems. The association with the diversification of crop production could also be driven indirectly from the income smoothing deriving from the additional wage for off-farm labor (Nguyen et al., 2017; Reardon, 1997a, 1997b). On the other hand, the wealthier and more educated households could be less risk adverse. As a result, they could be more willing to sacrifice crop failure risks for higher returns from specialization. Accordingly, the empirical findings are mixed. In Malawi, wealth is a driver for both crop and income diversification. The positive relationship between wealth and income diversification is confirmed in Zambia, while economic endowment is negatively associated with crop diversification in Zambia. As for human capital, more educated farmers exhibit a lower level of income diversification in Malawi while in Zambia more educated farmers tend to be more specialized in crop production and more diversified in terms of income sources. Notably, in Niger, neither wealth nor education are statistically significant drivers for the diversification of both crop production and the income sources. The cross-country differences are likely to arise from the combination of endogenous characteristics such as the risk attitude in context-specific structural features as well as the availability of alternatives to agricultural income, the average level of education and the quality of the institutions. Finally, receiving advice on sustainable and productivity-enhancing practices (either from governmental or private sources) is positively related with crop diversification in all the three countries. This speaks to the relevance of information availability and its beneficial effect on pulling smallholders toward more diversified farm systems.

6.2. Average effect of diversification on household welfare

This section presents the results on welfare outcomes of the two diversification strategies. The results have been obtained using several estimation techniques to test their robustness. Table 4 reports only the estimated coefficients associated with the diversification indices, which are the most relevant variables for this study.[11]

In Malawi, the results highlight that both crop and income diversification strategies improve household welfare outcome in all cases. The models assume that diversification choice is not correlated with household unobservable time-variant characteristics (RE, FE and CRE) yield very similar results: An increase by one percentage point of the crop diversification index determines an average increase of the household income of between 0.6 and 1%. Similarly, a marginal increase of income diversification is associated with 0.5–0.8% of total gross income, on average. In Niger, the average association between gross income and crop diversification is not statistically different from zero or even negative (−0.5%) according to the estimation procedure. Similarly, the average association between household gross income and diversification of the income sources is not statistically different from zero. In Zambia, the average association with household gross income varies from

[11] The complete results are available upon request. As for the instrumental variable estimates, it is worth noting that the tests reported in Appendix I support the robustness of the inference and when the structural model is over-identified the joint validity of the instruments.

Table 4
Average treatment effect by country and diversification strategy.

	Malawi				Niger				Zambia			
	RE	FE	CRE	IV-FE	RE	FE	CRE	IV-FE	RE	FE	CRE	IV-FE
Crop diversification	0.005***	0.008***	0.008***	0.018**	0.001	−0.005**	−0.005**	−0.006	0.001**	0.003***	0.003***	−0.072***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Individual effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	1497	1497	1497	780	1994	1994	1994	1092	9797	9797	9797	8884
Income diversification	0.003***	0.006***	0.006***	0.025**	−0.000	0.001	0.001	0.037*	0.006***	0.006***	0.007***	0.066***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Individual effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	1459	1459	1459	742	1688	1688	1688	822	9797	9797	9797	8884

Note: Significance levels (***p < 0.01, **p < 0.05, *p < 0.10).

0.1 to 0.3% for crop diversification and from 0.6 to 0.7% due to a 1% increase in income diversification.

All in all, these results highlight a certain degree of similarities between Malawi and Zambia while Niger seems to follow a different pattern. However, once the potential endogeneity related to the adoption of diversification strategies is addressed (IV-FE estimates), the cross-country heterogeneity increases also between Malawi and Zambia. On the one hand, in Malawi the instrumental variable findings highlight a downward bias in the previous estimates, although the general pathway does not change. In particular, the unbiased result shows that a marginal increase of the crop diversification index increases the household income by 1.8%, on average, while the same increase of the income diversification index induces an increase of 2.5%, on average. On the other hand, in Niger and Zambia, the instrumental variable estimates yield mixed results. While the impact of income diversification is always positive (3.7% in Niger and 6.6% in Zambia), those related to crop diversification are not statistically different from zero in Niger and turn out to be negative in Zambia (on average −7. 2%). These heterogeneous results are in line with the mixed findings from the literature about the effects of diversification strategies in these countries (see for example Asfaw et al., 2015 for Malawi; Asfaw et al., 2018 for Niger and Arslan et al., 2017 for Zambia).

The estimated cross-country differences depend on structural differences between the considered countries. Firstly, in Niger and Zambia the risk of extreme weather events is lower, the infrastructure is relatively more developed, and the markets are relatively more integrated. In this framework, the risk mitigation function related to crop diversification is less compelling and as a result, the expected benefits are lower.[12] Second, the average results are likely to conceal the heterogeneity between poor and rich farmers. In this case, the lack of benefits from crop diversification in Niger as well as its negative welfare effect in Zambia is likely to be led by the highly negative effect on the sub-sample of farmers who would have benefitted more from specialization. To disentangle these issues and shed more light on the impact of crop and income diversification on the household welfare within the selected countries, the next section will estimate the related effect at different quantiles of the income distribution (IV-FE QTE).

6.3. Assessing the heterogeneity of the effect across the income distribution

Few papers have successfully tested the hypothesis that the effect of crop and income diversification strategies on farm household welfare differs significantly between high- and low-income households (Asfaw et al., 2018; Zhao & Barry, 2014). Investigating the heterogeneous impact of diversification can help to identify policy options that are better tailored to the needs of a socio-economically diverse smallholder population. Furthermore, going beyond the average effect, the results are expected to be more homogeneous across countries since farmers located at the same point of the different country-specific income distribution are more likely to follow the same diversification pathway and to adopt similar strategies.

Table 5 reports the estimated coefficients associated with the three diversification indices at five points of the income distribution (quantiles 0.1, 0.25, 0.5, 0.75, 0.9). To ensure the comparability with the average results presented above, we first control only for the time-invariant unobserved heterogeneity (the results are reported in the columns denominated FE-QTE) and then we take also into account the potential endogeneity related to the selection bias (the results are reported in the columns denominated IV-FE QTE).[13] In what follows, only the latter results will be considered since they are assumed to be the unbiased one.

In Malawi, the impact of a marginal increase in crop and income diversification is higher at the bottom of the income distribution (1% in both the cases) and decreases monotonically moving toward the top of the distribution (0.1% and −0.4%, respectively). In Niger, the impact of crop diversification is positive only for the farmers located below the 10th percentile (0.4%) of the income distribution, while for the rest of the farmers is either not significantly different from zero or negative, up to −0.4% for farmers located at the 75th percentile. Similarly, the impact of a marginal increase in income diversification is the highest for the poorest and decreases monotonically moving toward the richest quantile (from 0.9% to −1.7%). A similar pattern is found for the impact of crop diversification in Zambia where, moving from the bottom to the top of the income distribution, the effect of a marginal increase in crop diversification monotonically decreases (from 0.7% to −0.3%). However, the impact of a marginal increase in income diversification is always positive and quite constant across the different quantiles, fluctuating between a maximum of 0.9% of the 10th percentile to a minimum of 0.7% (at the 90th percentile).

Overall, the findings from the quantile analysis reduce the cross-country heterogeneity detected in the previous section, allowing to draw several cross-country lessons from the empirical results. Firstly, the impact of diversification strategies is generally the highest for the poorest and the lowest at the top of the income distribution. Second, the impact of crop diversification at the top of the income distribution is often not statistically different from zero or even negative, highlighting that for the richest farmers the diversification of crop production could be detrimental. The impact

[12] Note that in countries where the risk of dry episodes is less contingent, the instrumental variable estimates enable to control for unobserved characteristics negatively related with crop diversification and positively related with household income such as entrepreneurial skills or the willingness to take risks. In this case, the baselines estimated are expected to be upwardly biased, explaining the negative coefficients associated with crop diversification.

[13] Figs. 2–4 in the appendix plot all the country-specific results from both the estimation techniques with the relative confidence intervals.

Table 5
Quantile treatment effect by country and strategy.

	Malawi		Niger		Zambia	
	QFE	QFE-IV	QFE	QFE-IV	QFE	QFE-IV
Crop diversification						
Q10%	0.010***	0.009***	0.002	0.004**	0.006***	0.007***
Q25%	0.009***	0.004***	−0.002*	−0.002	0.003***	0.003***
Q50%	0.006***	0.007***	0.000	0.001	−0.001***	0.002***
Q75%	0.003***	0.002**	0.002	−0.004**	−0.002***	−0.004***
Q90%	0.001*	0.001	0.001	0.001	−0.003***	−0.003***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes	yes	yes
Observations	1497		1994		9797	
Income diversification (off-farm + on-farm)						
Q10%	0.010***	0.010***	0.009*	0.009***	0.007***	0.009***
Q25%	0.011***	0.018***	0.013***	0.015	0.006***	0.008***
Q50%	0.003***	0.005***	0.001	0.002***	0.006***	0.008***
Q75%	0.000	−0.001**	−0.011***	−0.012***	0.005***	0.007***
Q90%	−0.004***	−0.002	−0.014***	−0.017***	0.006***	0.007***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes	yes	yes
Observations	1459		1688		9797	

Note: Significance levels (***p < 0.01, **p < 0.05, *p < 0.10).

of income diversification also tends to decline moving toward the top of the income distributions, although in Zambia the impact of such a strategy is always positive across all quantiles of the income distribution. This could be due to structural features such as better access to markets and better infrastructure (Bigsten & Tengstam, 2008). It is worth noting that while the interpretation of the results related to crop diversification is straightforward, that of the coefficients associated to income diversification is subject to some caveats. In particular, since the information available does not allow to distinguish among off-farm and on-farm activities with the same adequate granularity in the three countries considered, the estimated differences could be due to different prevalence of certain off-farm activities in each specific country.

7. Conclusions and policy implications

This paper aims to identify the drivers and impacts of crop and income diversification strategies on households' welfare in Malawi, Niger and Zambia. The study proposes a unique cross-country comparative perspective by analyzing the drivers and the impacts of each diversification dimension using standardized specifications and estimation techniques. Furthermore, it considers both the endogeneity due to selection bias and the potential heterogeneity characterizing the welfare impacts of diversification strategies at different levels of the income distribution.

The results show that the factors enabling a specific diversification strategy are mostly country-specific with only few variables, such as land size, information availability and the proximity to other diversified farmers that act as drivers across the different countries. Moreover, the exposure to extreme dry events acts as a push factor for crop diversification in Malawi and Niger and for income diversification in Zambia. As for the average welfare impacts, the empirical results highlight that, once having controlled for the selection bias, income diversification is a welfare-enhancing strategy in all the three countries analyzed. On the other hand, crop diversification increases household gross income only in Malawi, while it has no effect on the welfare of the Nigerien farmers and on average is a welfare decreasing strategy in Zambia. However, once the treatment effect is estimated at different quantiles of the income distribution, the results show that the impact of both diversification strategies is higher for the poorest (people located at the bottom tail of the distribution) and decreases, or even turns to be negative, moving toward the upper end of the income distribution, for all the three countries analyzed. This is probably due to the fact that the richest farmers have other available instruments to cope with production risk (in particular the risk related to climate shocks such as extreme weather events), while for the poorest, diversification is often the only viable alternative. Consequently, designing policies to promote diversification strategies is crucial to target the farmers who do not have access to other instruments to cope with external shocks. Incorrect targeting will have no impact on or will even reduce the welfare of farmers that would have benefitted more from specialization.

Some caveats related to the inherent nature of the synthetic diversification indexes deserve further comments. This study is not able to disentangle the nature of the diversification strategies synthesized into the diversification indexes. For example, crop diversification will equally increase whether maize production is integrated with a legume or with a cash crop. However, the expected impact of such a different farm system is clearly different. These limitations affect also the interpretation of the effect associated with the diversification of income sources. In order to have more detailed evidence about which particular diversification strategies benefit more the poor and which one are detrimental, detailed and comparable information on the nature of the off-farm activities are needed for all the countries included into the analysis. Despite these limitations, this analysis provides relevant indications to orient policy interventions aimed at enhancing household welfare through diversification strategies. Altogether, the focus on two different diversification strategies, the cross-country comparability, the consideration of endogeneity and the heterogeneity of the diversification effects contribute to innovation on the previous literature on this topic. Investigating the impact of the specific strategies underlying the synthetic diversification indexes will be a fruitful area of research for further contributions.

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Appendix I Focus on the instrumental fixed effect estimator

Table A-1.

Table A-1
First stage results from the average instrumental variable fixed effect estimator.

	Crop	Income (off-farm + on-farm)	Crop	Income (off-farm + on-farm)	Crop	Income (off-farm + on-farm)
Climatic variables						
Long-term risk of negative rainfall shocks	−1.710	−0.604	7.680***	−1.227	1.233***	−1.355***
	(1.681)	(1.746)	(1.058)	(1.444)	(0.334)	(0.378)
Peer effects						
% diversification index within the EA	0.357***	0.311***	–	–	–	–
	(0.076)	(0.092)	–	–	–	–
HH Socio demographic						
Age of Household Head	−0.307	−0.009	0.067	0.280*	−0.156**	0.217**
	(0.263)	(0.266)	(0.142)	(0.167)	(0.076)	(0.086)
Household size	−0.281	1.001	0.235	0.682	−0.269	1.000***
	(0.946)	(0.974)	(0.476)	(0.550)	(0.230)	(0.260)
Female Household Head	5.155	−2.567	−1.759	−1.969	−4.317**	3.351
	(5.908)	(6.212)	(3.349)	(4.011)	(1.899)	(2.147)
Human, natural and physical capital						
Household head level of education	−0.025	0.262	−0.342	−1.606***	0.242	0.073
	(0.726)	(0.765)	(0.355)	(0.408)	(0.153)	(0.173)
Land size	14.176***	0.403	0.041	−0.042	0.861***	−0.462**
	(3.193)	(3.321)	(0.240)	(0.302)	(0.197)	(0.223)
Wealth Index	1.790	7.969	58.245*	61.396	5.972***	14.511***
Institutions and infrastructures						
Agriculture Extension officer	1.201	3.206	4.069	1.341	0.441	1.600**
	(2.153)	(2.217)	(4.205)	(5.255)	(0.617)	(0.698)
Distance from periodic the market	−0.521**	−0.021	−0.121***	−0.109**	−0.020	−0.040**
	(0.232)	(0.243)	(0.032)	(0.044)	(0.016)	(0.018)
Distance from the road	2.224*	−0.186	0.043	−0.040	0.033**	0.012
	(1.221)	(1.269)	(0.031)	(0.042)	(0.016)	(0.018)
Regional/AEZ dummies	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Individual Fixed effect	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
F	11.496	5.777	52.715	5.392	13.587	12.847
IDSTAT	22.362	11.568	48.890	10.790	13.576	12.839
ID-P	0.000	0.003	0.000	0.005	0.000	0.000
ARF	2.607	2.698	0.528	2.729	47.443	47.443
ARF-P	0.075	0.069	–	0.066	0.000	0.000
SSTAT	5.306	5.494	0.538	5.533	47.046	47.046
SSTAT-P	0.070	0.064	–	0.063	0.000	0.000
SARGAN	0.033	0.204	0.000	0.352	0.000	0.000
SARGAN-P	0.855	0.651	–	0.553	–	–
Observations	780	742	1092	822	8884	8884

Note: Significance levels (***p < 0.01, **p < 0.05, *p < 0.10).

Appendix II Graphical analysis of the results from the quantile treatment effect models by country and strategies

Figs. A-1–A-3.

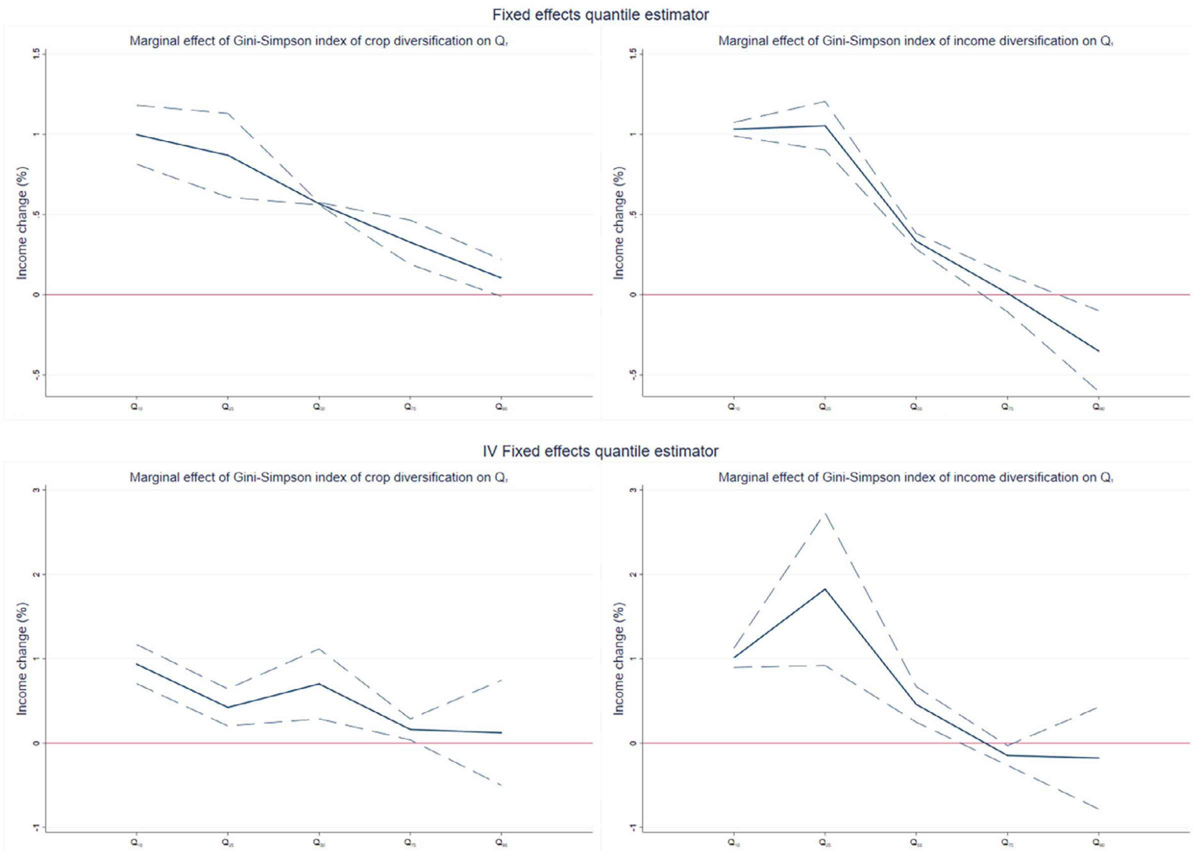

Fig. A-1. Marginal treatment effect of crop and income diversification in Malawi.

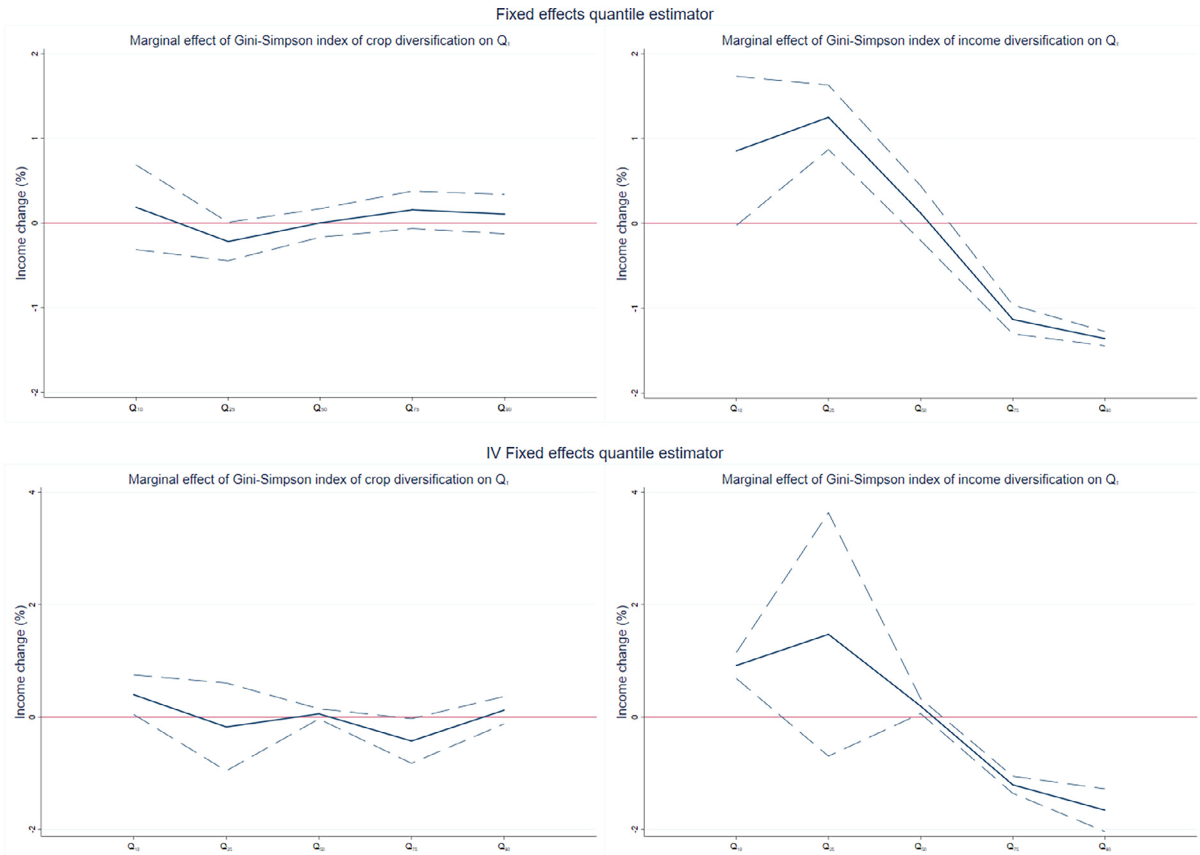

Fig. A-2. Marginal treatment effect of crop and income diversification in Niger.

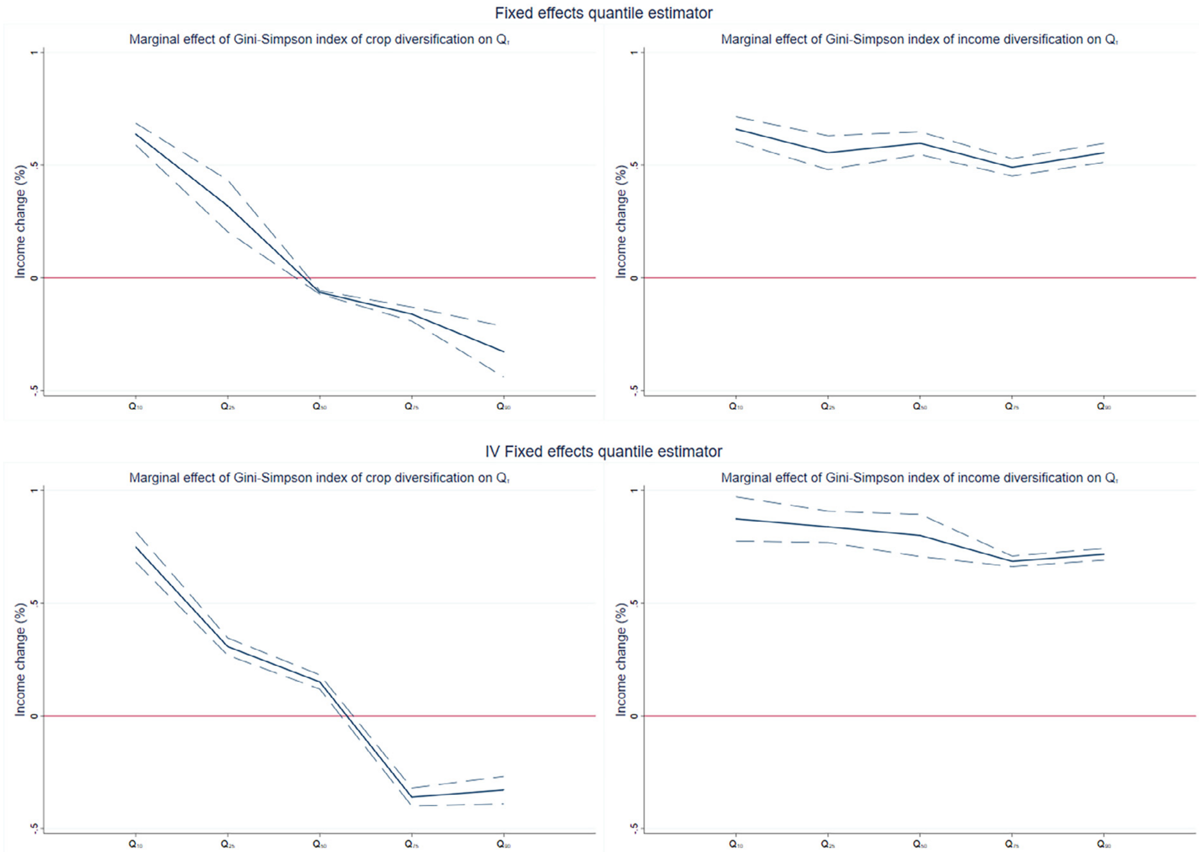

Fig. A-3. Marginal treatment effect of crop and income diversification in Zambia.

Appendix III Robustness check using the off-farm income diversification index (complete results)

Tables A-2–A-4.
Figs. A-4–A6.

Table A-2
Drivers and constraints by country and diversification strategy.

	Malawi		Niger		Zambia	
	Crop	Income (off-farm)	Crop	Income (off-farm)	Crop	Income (off-farm)
Climatic variables						
Long-term risk of negative rainfall shocks	0.460**	0.007	0.796***	0.068	−0.752***	−0.050
Peer effects						
% of crop diversification within the EA	0.368***	0.035	0.431***	−0.052*	0.538***	0.016
% of income diversification (off-farm) within the EA	0.028	0.240***	0.073***	0.208***	0.007	0.074***
HH Socio demographic						
Age of Household Head	−0.153***	−0.068*	0.025	0.092***	0.029***	0.022
Household size	0.311	0.880***	−0.049	0.169	(0.011)	(0.014)
Female Household Head	0.779	−0.253	1.479	0.157	−0.034	0.344***
Human, natural and physical capital						
Household head level of education	−0.179	−0.389**	0.138	−0.075	−0.316***	0.203***
Land size	13.087***	−1.662	12.532	14.072	0.850***	−0.738***
Wealth Index	10.246***	0.382	7.839***	−2.054	−2.464**	2.895**
Institutions and infrastructures						
Agriculture Extension officer	2.955**	2.203	7.839***	−2.054	0.855**	1.491***
Market access (distance from periodic the market)	−0.178**	−0.011	−0.008	−0.014	0.001	−0.021**
Road access (distance from the road)	0.150**	0.019	0.011	0.028	0.010	−0.011
Year dummy	YES	YES	YES	YES	YES	YES
Regional/AEZ dummies	YES	YES	YES	YES	YES	YES
Random effects	YES	YES	YES	YES	YES	YES
Simultaneous estimates	YES	YES	YES	YES	YES	YES
Observations	1387		1658		7183	

Note: Significance levels (***p < 0.01, **p < 0.05, *p < 0.10).

Table A-3
Average treatment effect by country and diversification strategy.

	Malawi				Niger				Zambia			
	RE	FE	CRE	IV-FE	RE	FE	CRE	IV-FE	RE	FE	CRE	IV-FE
Crop diversification	0.005***	0.008***	0.008***	0.018**	0.001	−0.005**	−0.005**	−0.006	0.001**	0.003***	0.003***	−0.072***
Regional/EZ dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Individual effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	1497	1497	1497	780	1994	1994	1994	1092	9797	9797	9797	8884
Income diversification (off-farm + on-farm)	0.003***	0.006***	0.006***	0.025**	−0.000	0.001	0.001	0.037*	0.006***	0.006***	0.007***	0.066***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Individual effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	1459	1459	1459	742	1688	1688	1688	822	9797	9797	9797	8884
Income diversification (off-farm only)	0.004***	0.007***	0.008***	0.031**	0.002*	0.002	0.002	0.007	0.001*	0.002***	0.002***	0.212
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Individual effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	1368	1368	1368	642	1688	1688	1688	822	7037	7037	7037	4858

Note: Significance levels (***p < 0.01, **p < 0.05, *p < 0.10).

Table A-4
Quantile treatment effect by country and strategy.

	Malawi		Niger		Zambia	
	QFE	QFE-IV	QFE	QFE-IV	QFE	QFE-IV
Crop diversification						
Q10%	0.010***	0.009***	0.002	0.004**	0.006***	0.007***
Q25%	0.009***	0.004***	−0.002*	−0.002	0.003***	0.003***
Q50%	0.006***	0.007***	0.000	0.001	−0.001***	0.002***
Q75%	0.003***	0.002**	0.002	−0.004**	−0.002***	−0.004***
Q90%	0.001*	0.001	0.001	0.001	−0.003***	−0.003***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes	yes	yes
Observations	1497		1994		9797	
Income diversification (off-farm + on-farm)						
Q10%	0.010***	0.010***	0.009*	0.009***	0.007***	0.009***
Q25%	0.011***	0.018***	0.013***	0.015	0.006***	0.008***
Q50%	0.003***	0.005***	0.001	0.002***	0.006***	0.008***
Q75%	0.000	−0.001**	−0.011***	−0.012***	0.005***	0.007***
Q90%	−0.004***	−0.002	−0.014***	−0.017***	0.006***	0.007***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes	yes	yes
Observations	1459		1688		9797	
Income diversification (off-farm only)						
Q10%	0.005***	0.004***	0.004***	0.006***	0.002**	0.007***
Q25%	0.010***	0.009***	0.003***	0.003	−0.001	−0.005**
Q50%	0.006***	0.005***	0.002**	−0.000	−0.001***	0.002***
Q75%	0.003***	0.001	0.004	0.000	−0.001***	−0.002***
Q90%	−0.001	−0.007	0.000	−0.008	0.001***	0.004***
Regional/AEZ dummies	yes	yes	yes	yes	yes	yes
Individual fixed effects	yes	yes	yes	yes	yes	yes
Observations	1368		1688		7037	

Note: Significance levels ($^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$).

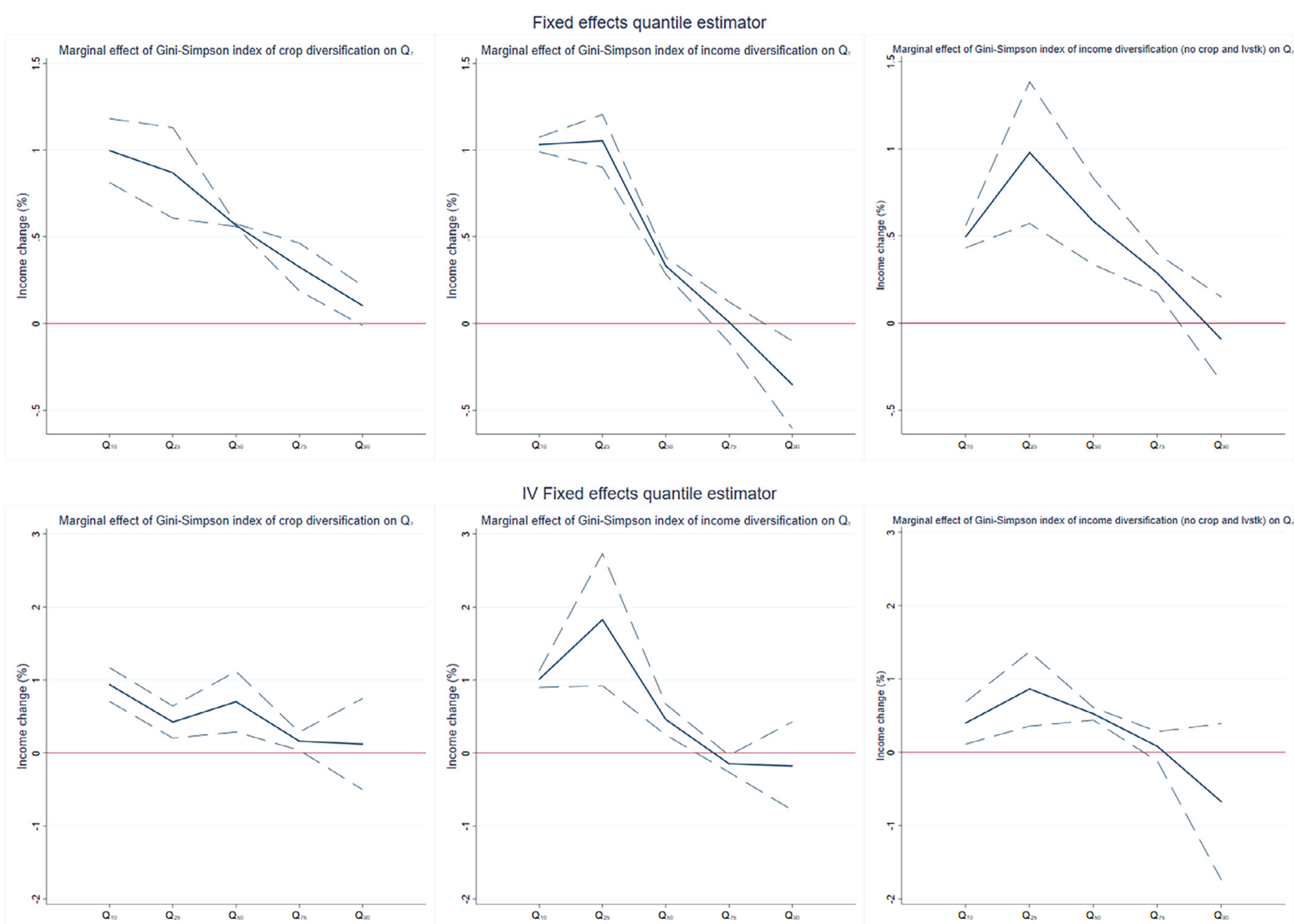

Fig. A-4. Marginal treatment effect of crop and income (off-farm + on-farm) and income (off-fam only) diversification in Malawi.

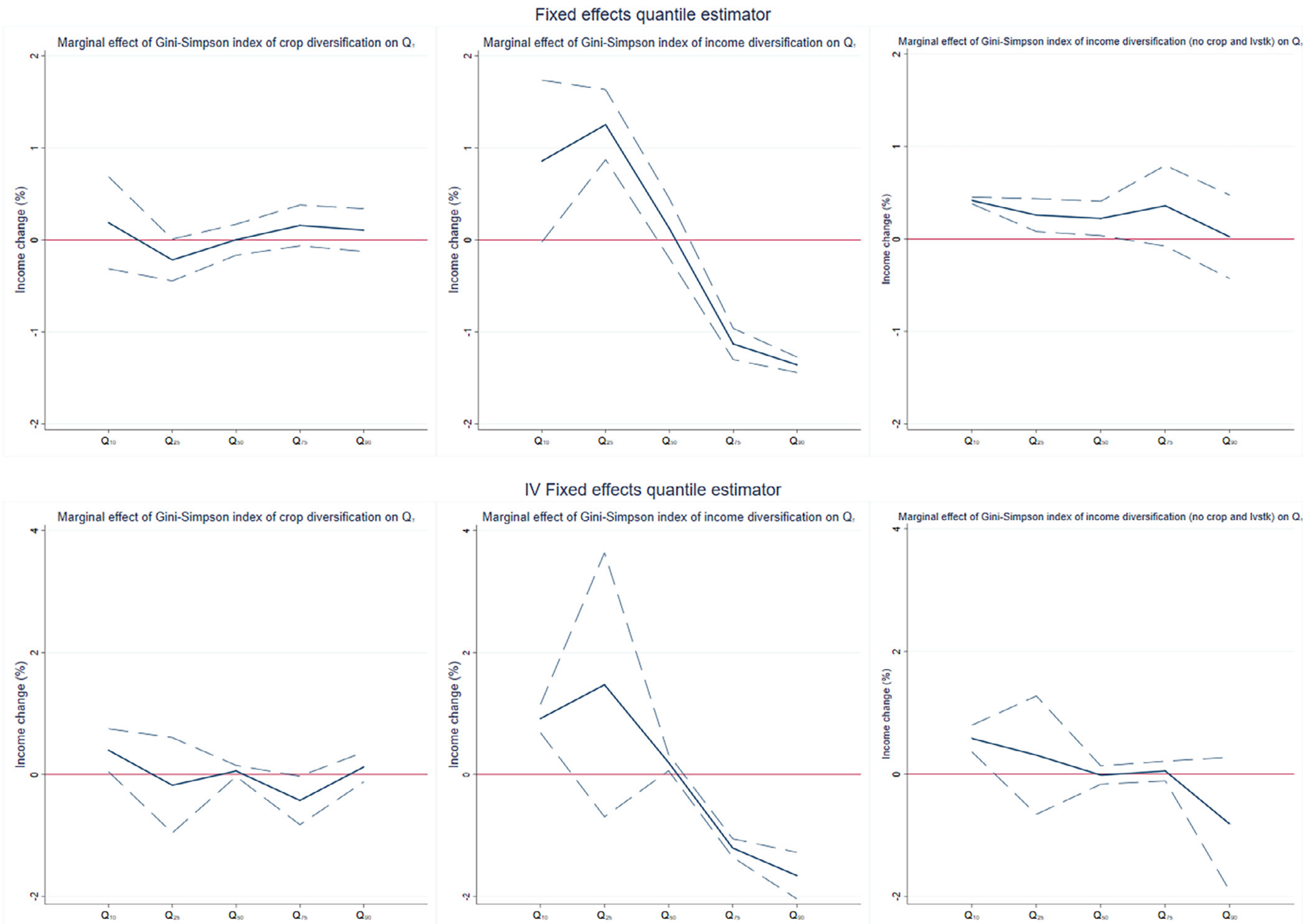

Fig. A-5. Marginal treatment effect of crop, income (off-farm + on-farm) and income (off-fam only) diversification in Niger.

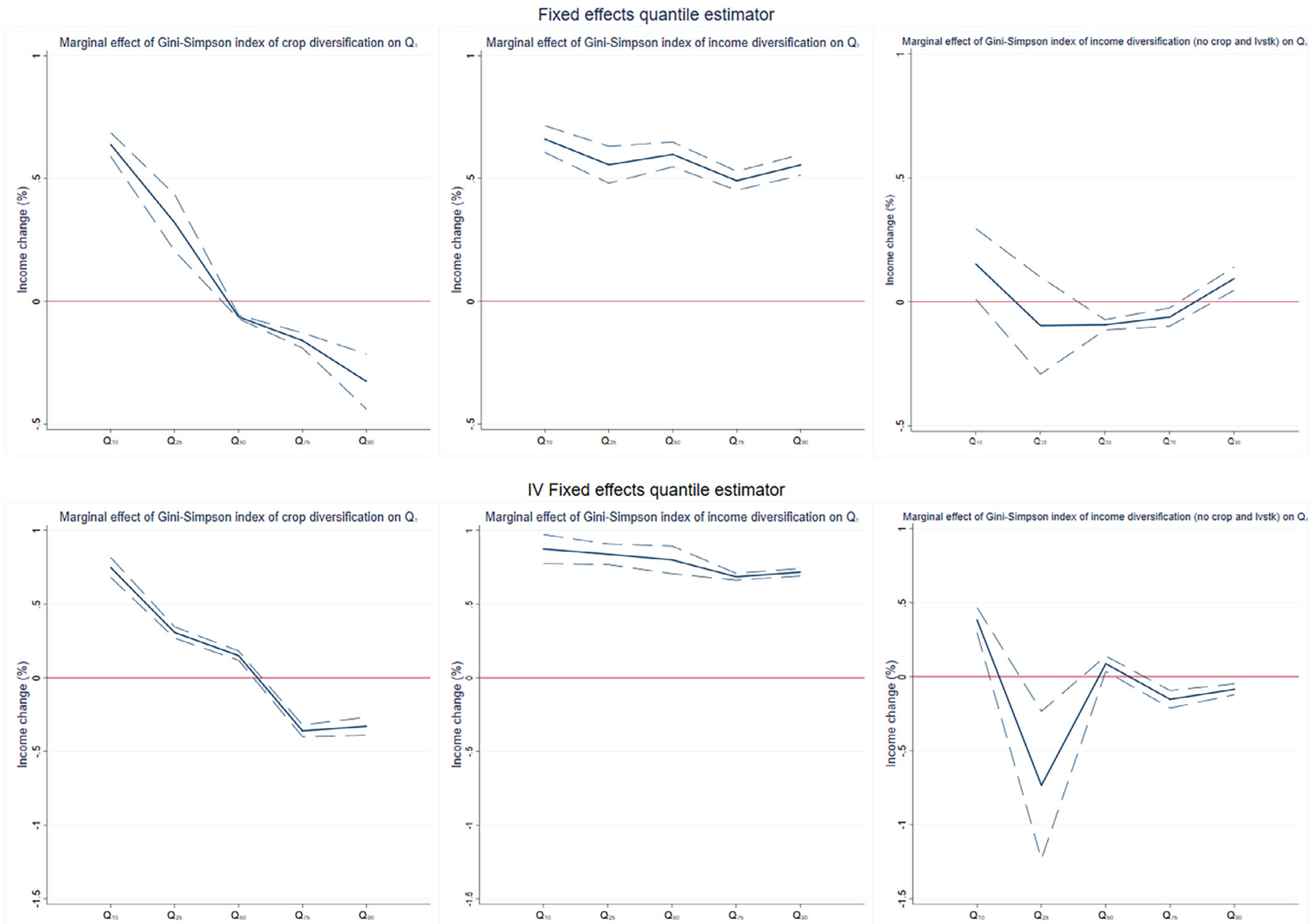

Fig. A-6. Marginal treatment effect of crop, income (off-farm + On-farm) and income (off-fam only) diversification in Zambia.

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